High Pressure Standards Based on Compact Piston Gauges

NIST provides world-class standards for pressure measurements through development of innovative approaches to realization of those standards. The purpose of the work described here is to determine the performance of piston/cylinder assemblies (i.e., piston gauges) operating at high pressures, thereby establishing their utility as primary pressure standards. The ultimate goal is to realize the unit of pressure, the pascal, and transfer the unit of pressure to our customers at the lowest uncertainty possible to satisfy customer needs in aviation, weather prediction, safety considerations affecting many industries using processes where pressure control and regulation and safety of containment structures are critical considerations in both design and operation.

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The accurate measurement of pressure is required for determining the altitude of aircraft, measuring barometric pressure for weather prediction, optimizing the performance of engines and industrial processes, and process control in manufacturing. At pressures ranging from atmospheric to very high pressures, piston gauges are used as primary and secondary pressure standards at National Metrology Institutes as the basis for national and international pressure scales. In the pneumatic region below 1 MPa, large diameter piston gauges supported with improved dimensional capability and manometric pressure standards make it possible to achieve a relative standard uncertainty in pressure of a few parts in 10^6. Uncertainties in the hydraulic pressure region can be significantly higher, in particular above 100 MPa. In the past, hydraulic piston gauge standards have used very large mass loads (400 kg or more). We have been studying the performance of a new generation of compact piston gauges that offer the potential for reduced uncertainties. The gauges have a smaller, integrated design, and use existing mass sets.

For the first time, international comparisons can be contemplated using direct comparison of primary standards, rather than with a secondary transfer standard.

Recently, two US manufacturers have provided to NIST compact piston gauges of the "controlled-clearance" type. This class of piston gauges uses an auxiliary pressure to "control" the distortion of the cylinder element, which becomes significant above 10 atmospheres of pressure. The use of auxiliary pressure also allows establishing the gauge as an independent, primary standard. We have made extensive performance measurements of the first of these two piston gauges [1], which operates to 200 MPa. This gauge uses a common 100 kg mass set, is easily transportable, and is based on a commercial line of piston gauges with modern PC-based controls and protocols. The cylinder was designed for minimal vertical loading, which allows its experimental distortion to more closely match that from elasticity theory of solids deformation.

The compact piston gauge has shown excellent repeatability over a two-year period (relative agreement of 1.1×10^{-6} in the effective area). The gauge also agrees to the present NIST pressure scale to better than its standard uncertainty, with a maximum deviation of 22 ppm through NIST gauge PG21and 33 ppm through NIST gauge PG479. The figure shows the agreement between the effective area from the characterization equation and the area from direct comparison to the present NIST pressure scale.

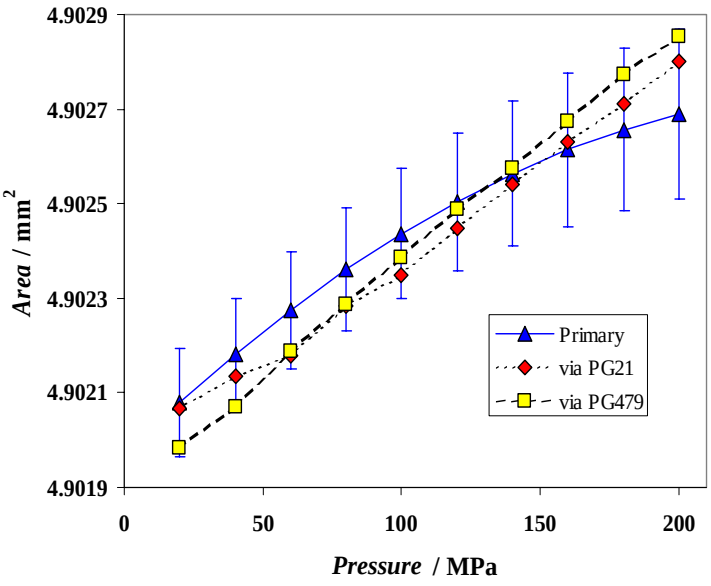

Figure 1. ***Comparison of the effective area from characterization method (Primary) to that from the present NIST pressure scale (via PG21 and via PG479), for new compact controlled clearance piston gauge. Areas agree to within standard uncertainty of the compact gauge throughout the pressure range.***

Impact

The compact design of these piston gauges supports easy shipment to other installations and makes them excellent candidates for use as pressure transfer standards. Ease of use will also allow more frequent checks at NIST of the primary standard against NIST secondary standards, or perhaps direct calibration of customer gauges against the primary standard.

Future plans

This year, NIST will begin studying the performance of the second of the two controlled clearance piston gauges from the US manufacturers. This gauge can operate to higher pressure (280 MPa vs 200 MPa), more closely matching the range of NIST secondary standards.

Publications:

A.K. Bandyopadhyay and D.A. Olson, **"Characterization of a compact 200 MPa controlled clearance piston gauge as a primary pressure standard using the Heydemann and Welch method"**, *Metrologia* **43**, 573-582 (2006).